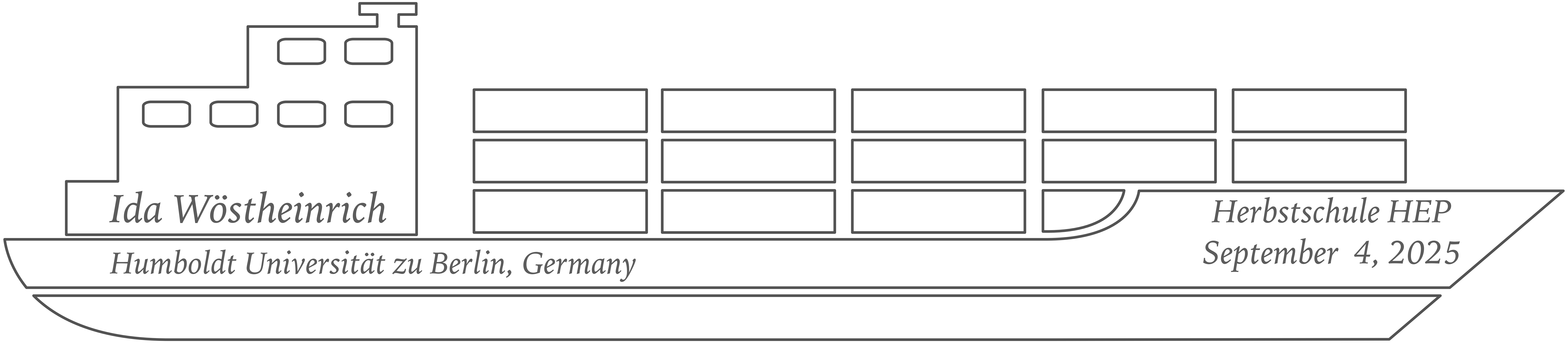
THE SURROUNDING BACKGROUND TAGGER: BUILDING SHIP'S VETO SHIELD



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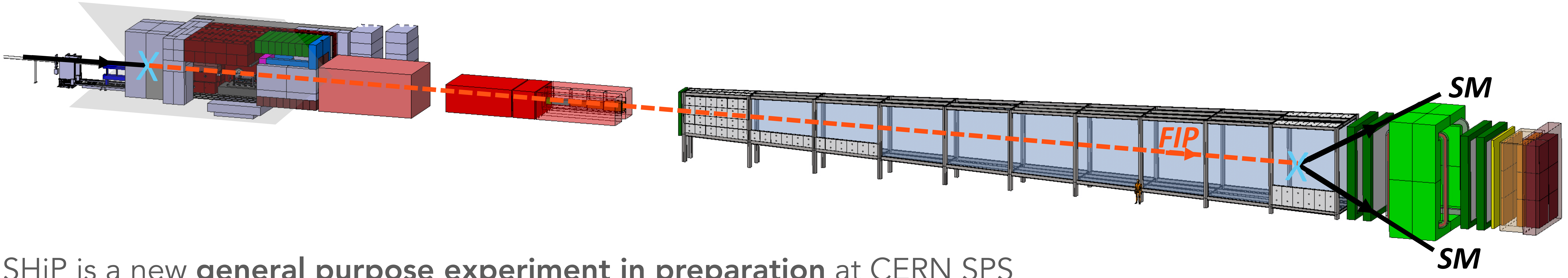
Herbstschule HEP

September 4, 2025

SEARCH FOR HIDDEN PARTICLES (SHIP): STATUS AND GOAL

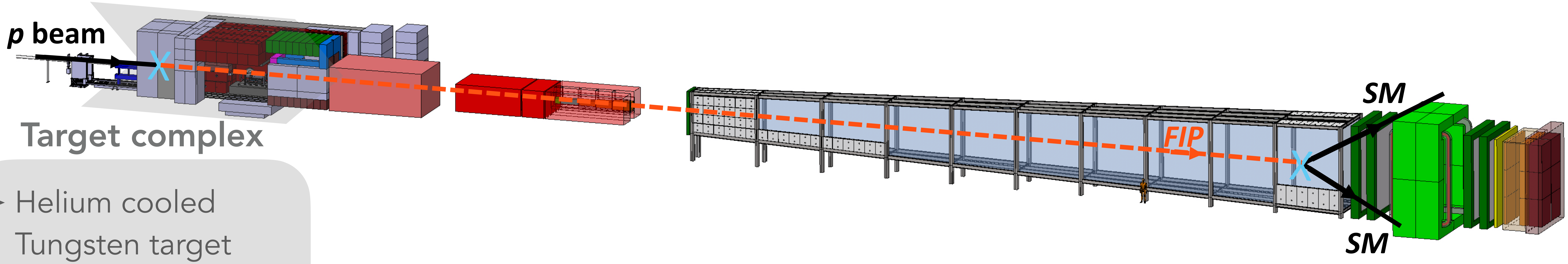


- SHiP is a new **general purpose experiment in preparation** at CERN SPS (Super Proton Synchrotron) high-intensity beam dump facility

GOAL:
- Comprehensive search for **feebly interacting particles (*FIPs*)** at **mass range (0.5 – 5) GeV/c²** over **several orders of magnitude in coupling** performed in a **near zero background environment**
  - f.e. Heavy Neutral Leptons (HNL), Dark photons, Dark scalars …

STATUS:
- Proposed in 2023, **approved for Technical Design Report (TDR) preparation in 2024**
- Transition towards implementation - **TDR expected by 2027**
- **First data-taking planned for 2031-2033**

THE SHIP DETECTOR



Target complex

- Helium cooled Tungsten target
- Cast iron & concrete shielding
- Magnetised hadron stopper

Per year:

- $\approx 10^{17}$ charmed hadrons
- $\approx 10^{17}$ beauty hadrons
- $\mathcal{O}(10^4)$ ν_τ interactions in **SND**

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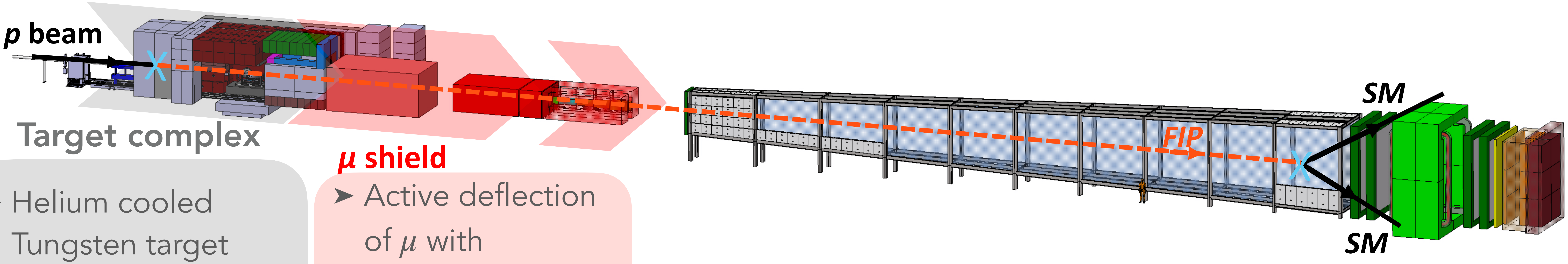

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μ shield

- Active deflection of μ with $E > 10\,\mathrm{GeV}$

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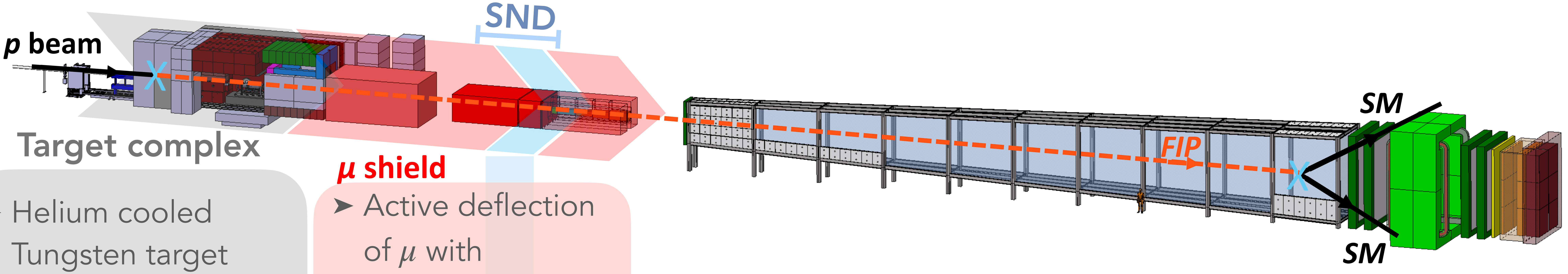

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Scattering and Neutrino Detector (SND)

- Direct search for light dark matter for via nuclear & electron recoils
- Strong neutrino program focused on ν_τ -physics

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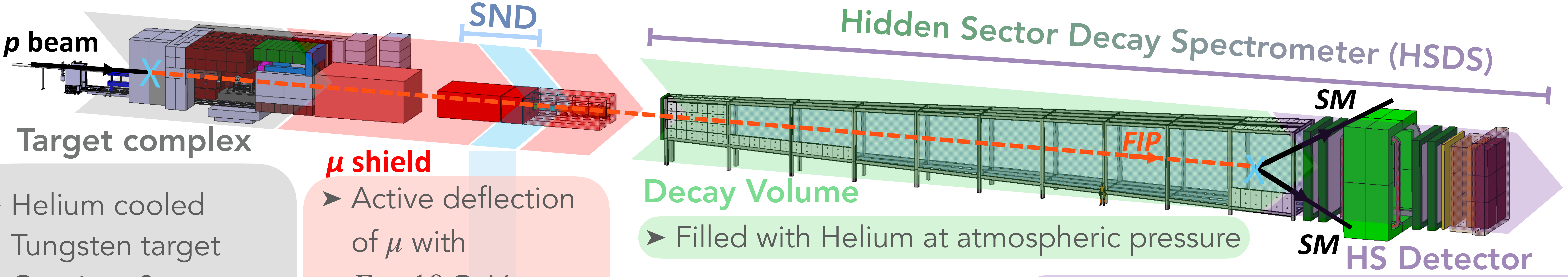

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Decay Volume

- Filled with Helium at atmospheric pressure

HS Detector

- Spectrometer Straw Tracker & Magnet

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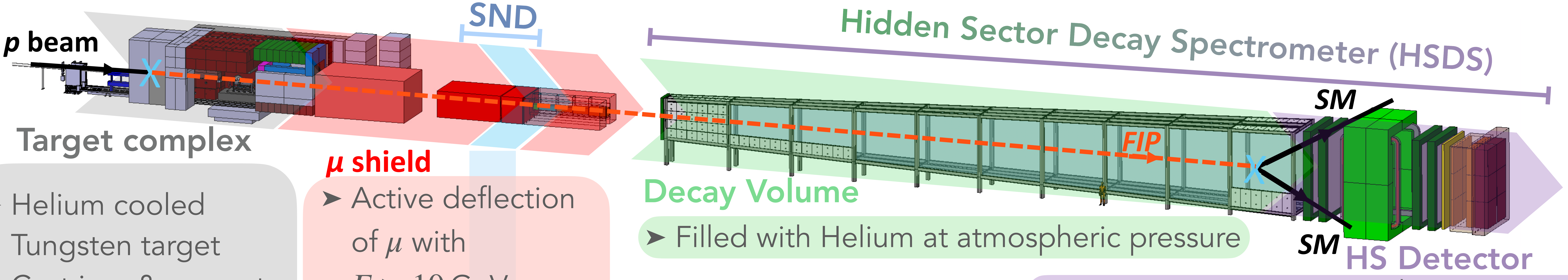

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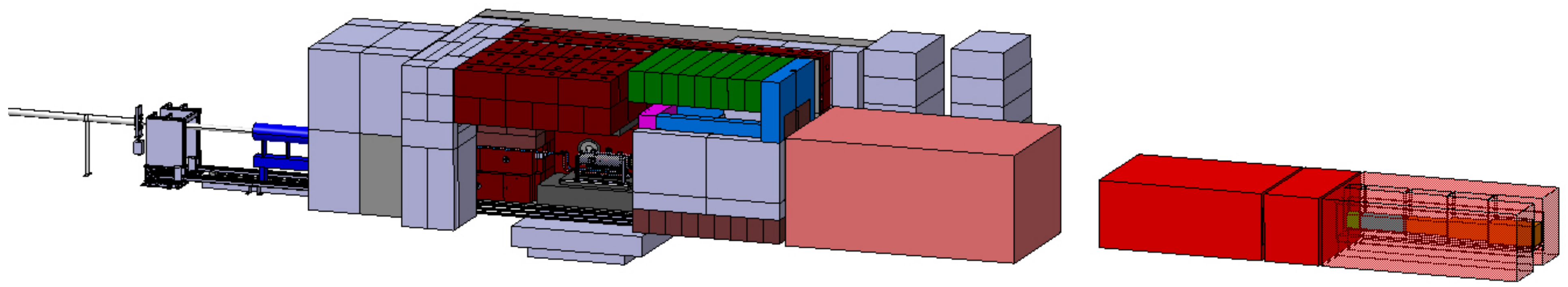
- Search for FIPs with the **Hidden Sector Decay Spectrometer (HSDS)** in a **near-zero background environment**

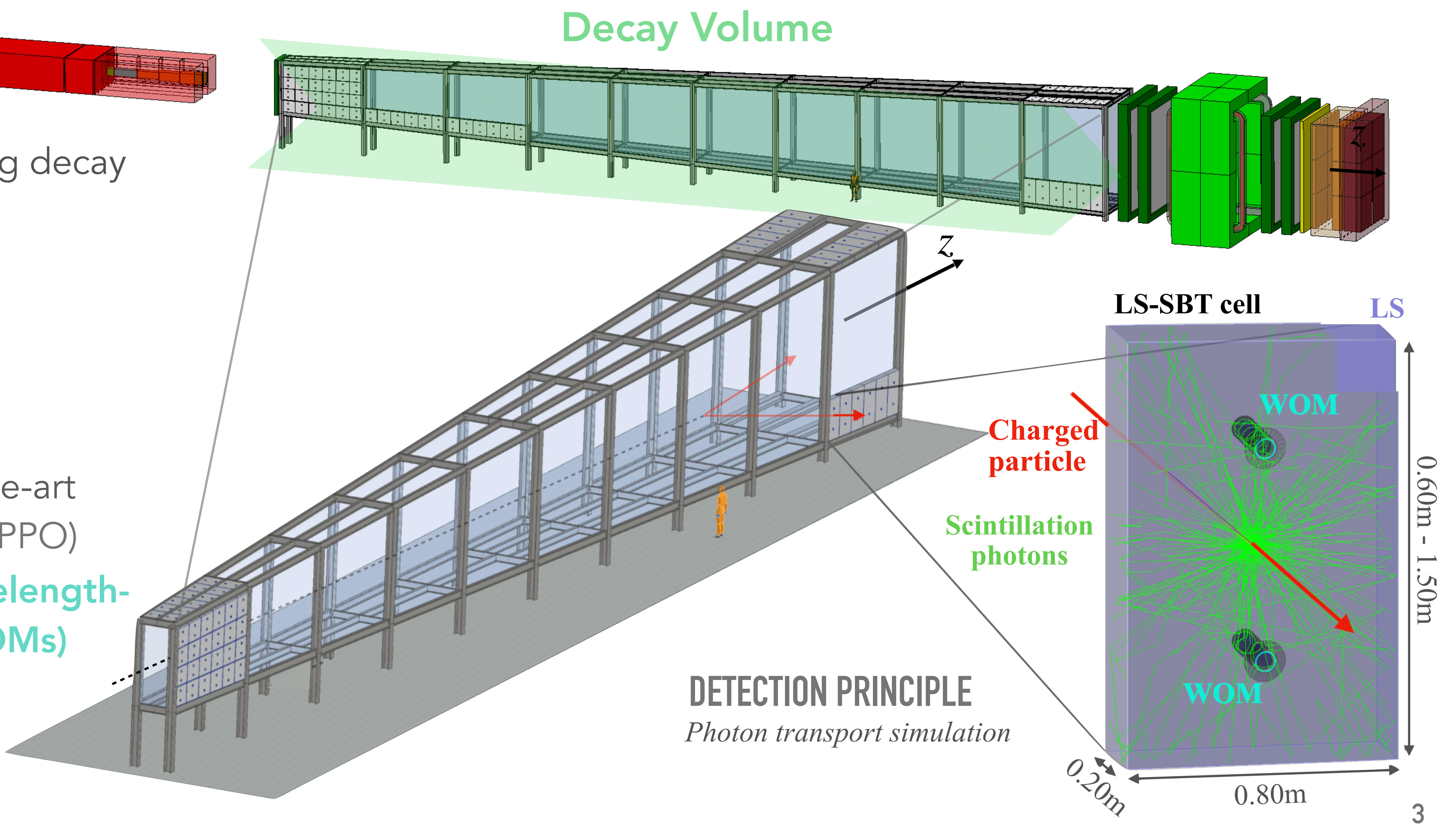
Remaining backgrounds in HSDS after shielding:

- Neutrino Deep Inelastic Scattering
- Muon Deep Inelastic Scattering
- Muon Combinatorial

SURROUNDING BACKGROUND TAGGER (SBT)

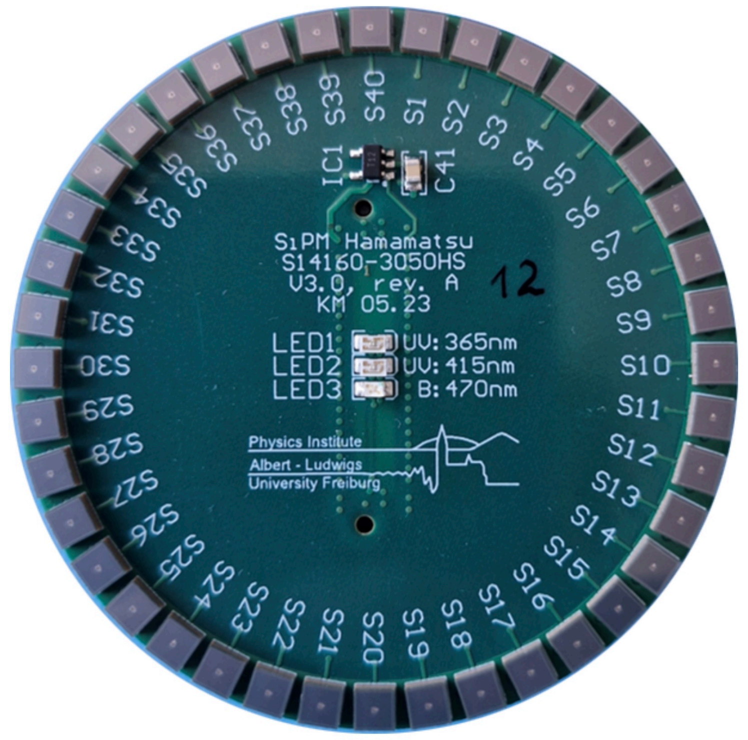


- Tags **charged particles** entering decay vessel
- Discrimination against μ- and ν-induced Background
- **Segmented geometry:** ~800 cells
- Filled with **145 000l** state-of-the-art **Liquid Scintillator (LS)** (LAB + PPO)
- Instrumented with ~1600 **Wavelength-Shifting Optical Modules (WOMs)**



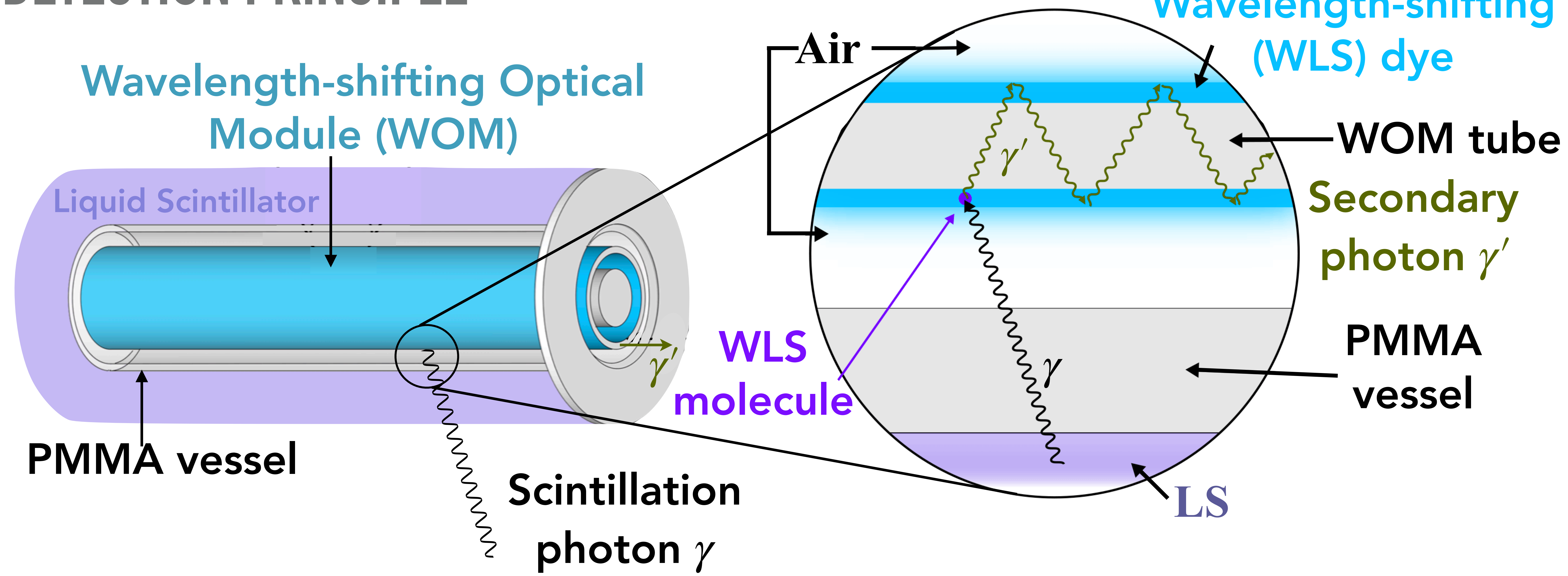
WAVELENGTH SHIFTING OPTICAL MODULE (WOM)

- PMMA (Plexiglas) tubes coated with **wavelength-shifting (WLS) dye** (PEMA + p-Terphenyl + bis-MSB)
- Read out by **circular arrays of Silicon photomultipliers (SiPMs)**

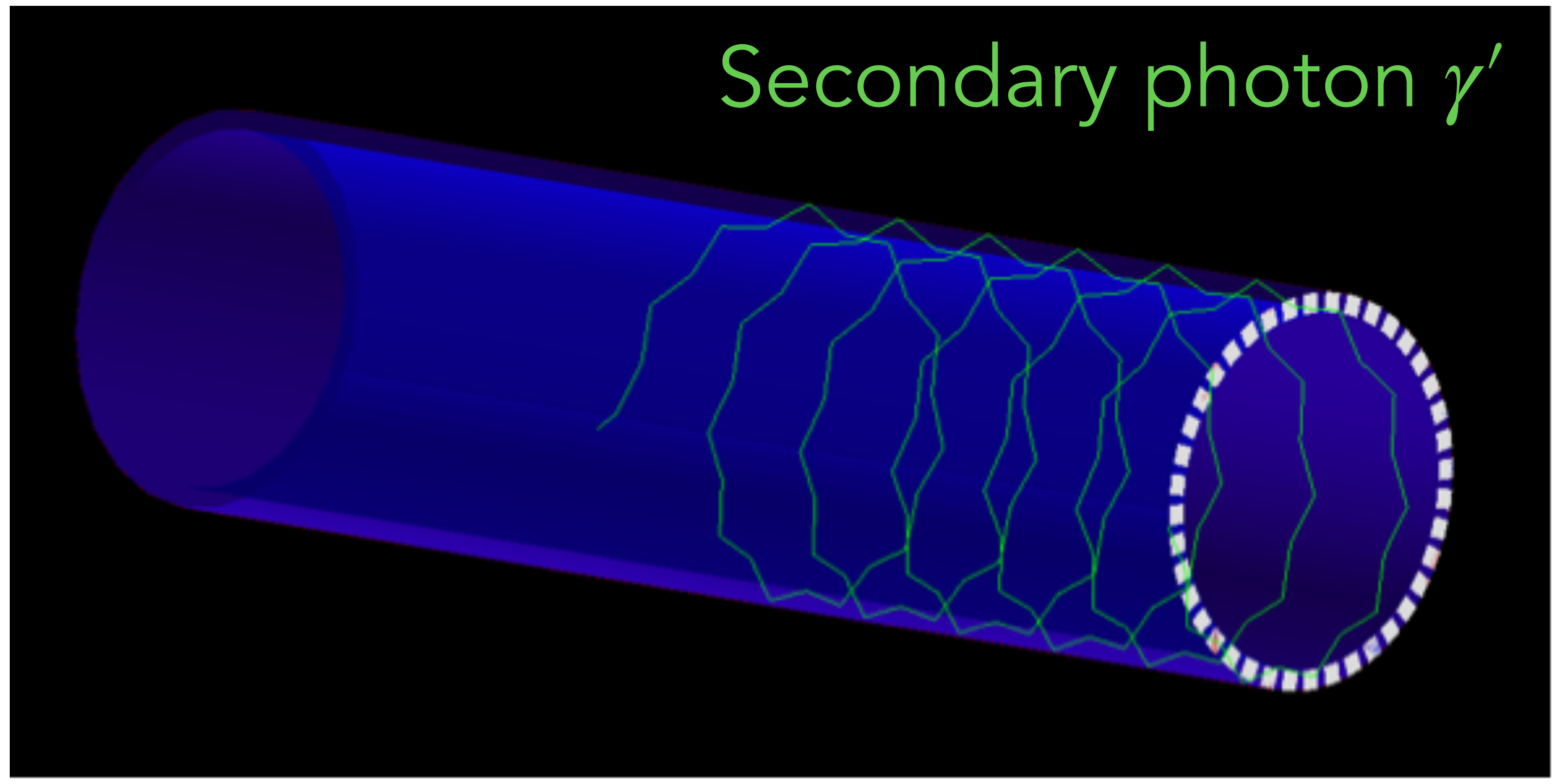


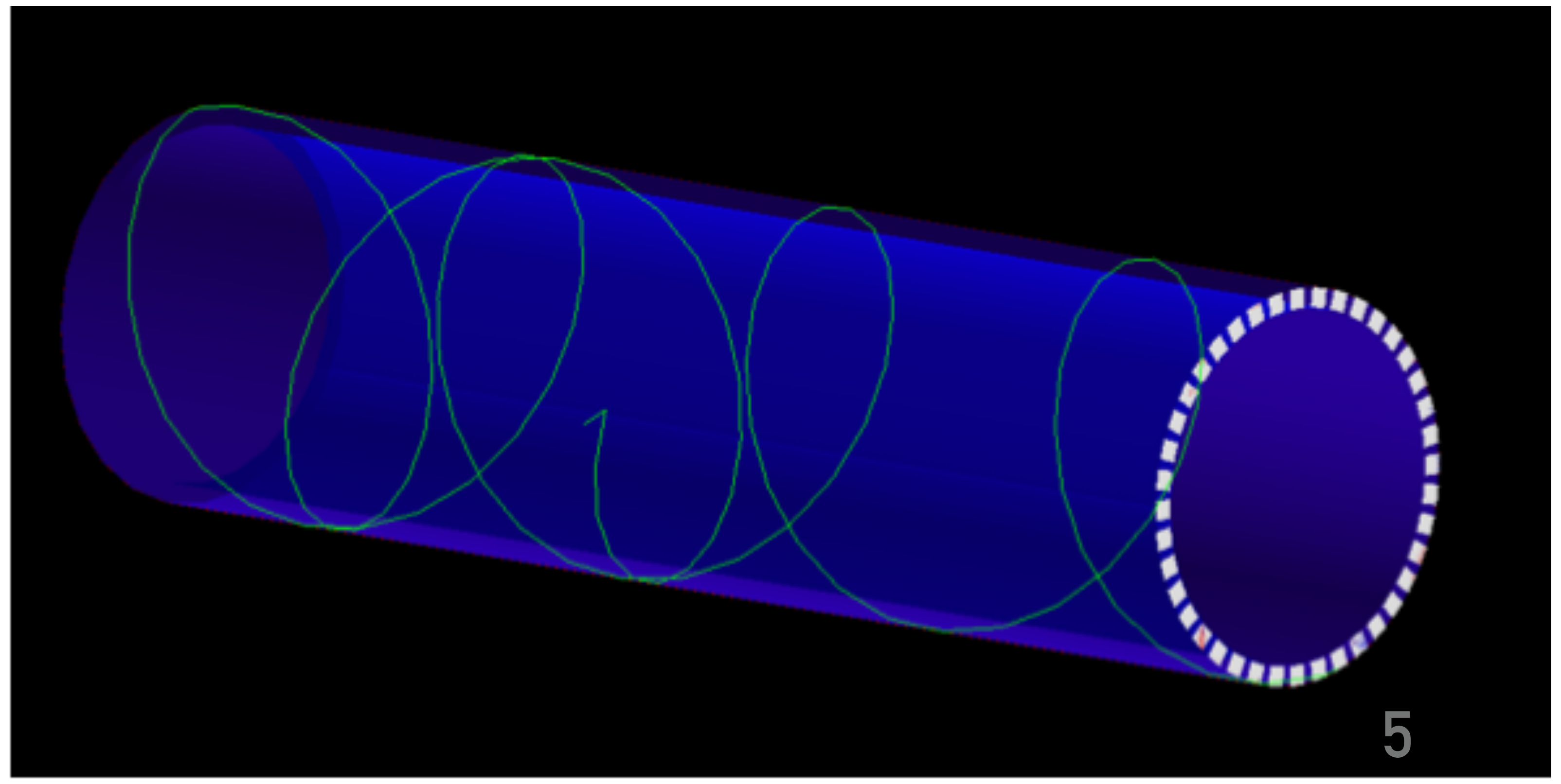
- **Cost-effective alternative** to conventional photomultipliers
- About **1600 WOMs** will be installed
- Reliable production and **quality control** essential.

DETECTION PRINCIPLE



PHOTON TRANSPORT SIMULATIONS





TECHNICAL DESIGN PHASE

By 2027 we need:

Detailed engineering design

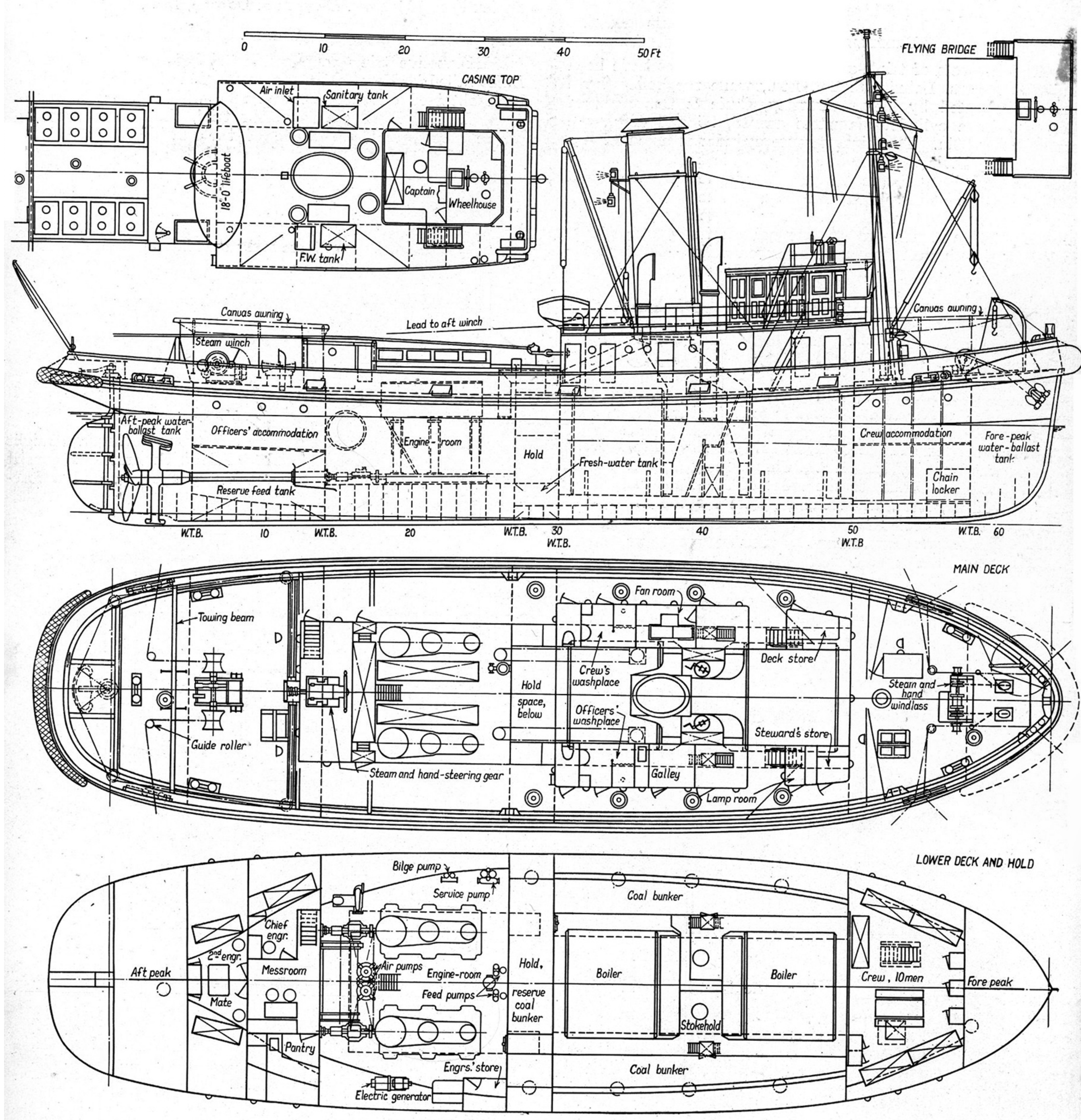
- materials, dimensions, mechanics, electronics, read out…

Validate performance goals

- test-beam results, signal and background simulation studies …

Costs, schedule, risks

- Cost estimate, production schedule, risk assessment …



https://daldy.co.nz/wp-content/uploads/2018/10/plan_small.jpg

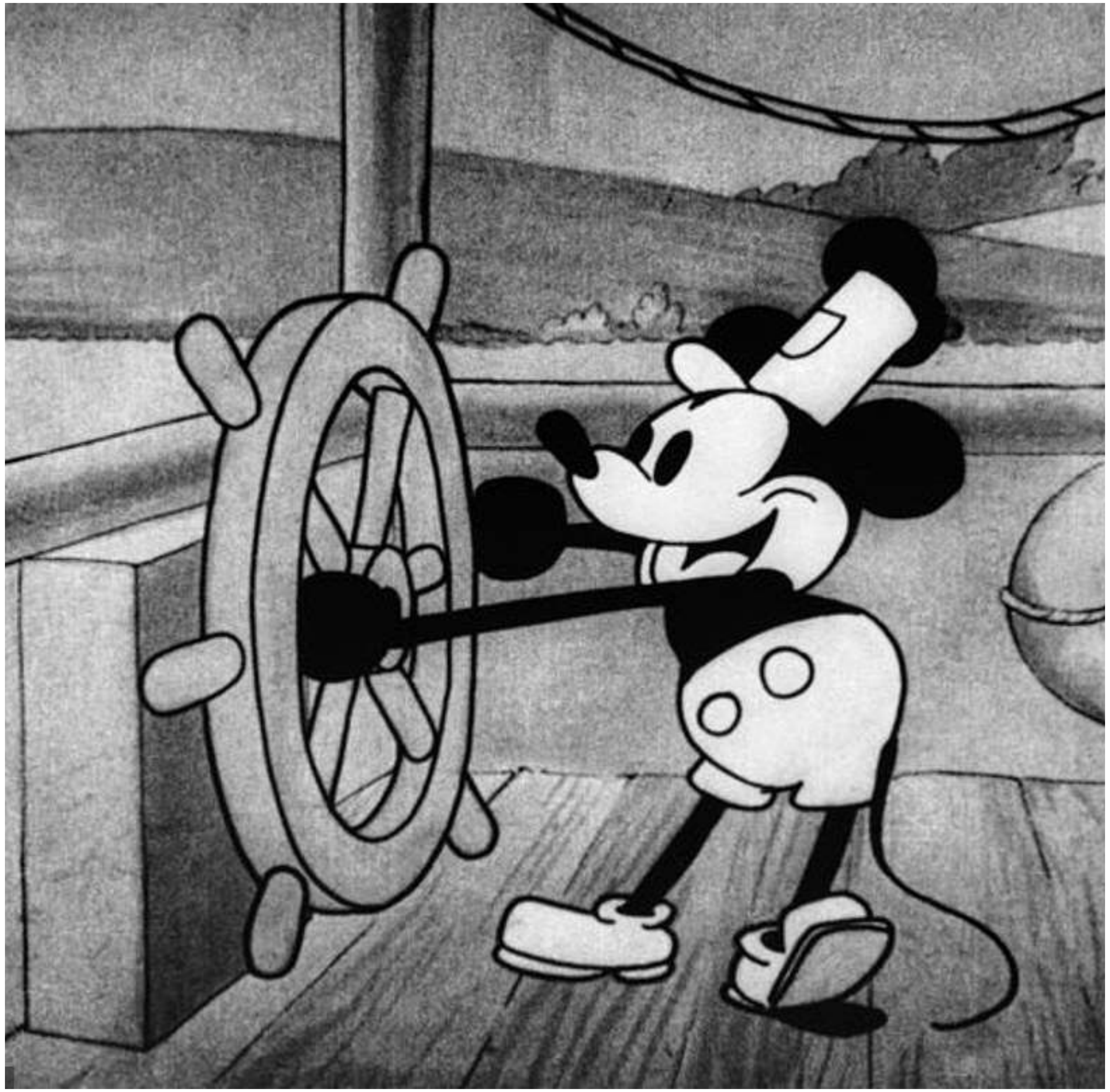
THESIS PROJECT IDEAS

Technical Design Report (TDR) preparation

- Participation in SBT test-beam campaigns at CERN
- Preparation of WOM quality control
- Documentation for the TDR
- Start of WOM mass production (from early 2028)

Physics analysis

- Simulation studies of background processes
- Benchmark signal processes ($N \to$ Multibody) with kinematic reconstruction of the mass peak



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THESIS PROJECT IDEAS

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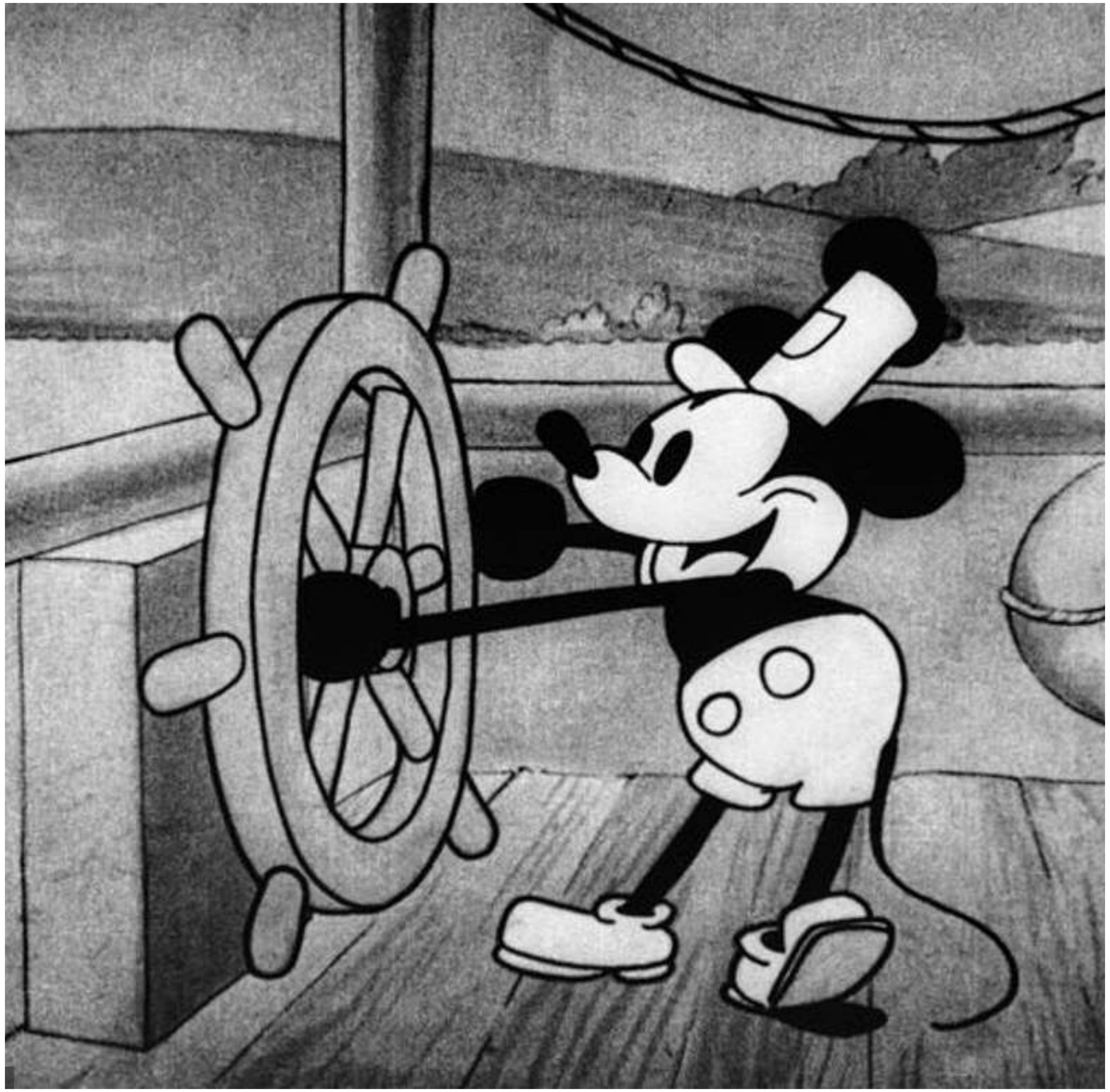

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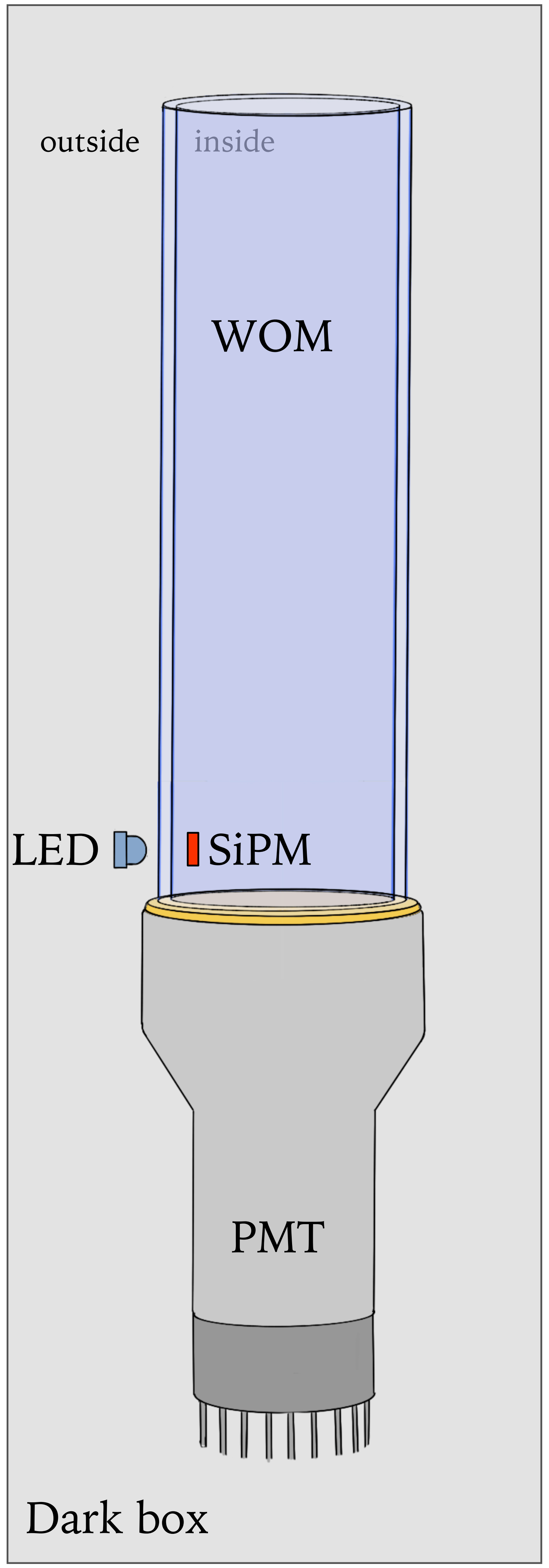
FOLLOWING UP ON MASTER THESIS: WOM QUALITY CONTROL

- Measuring absorption efficiency and homogenity of the WLS dye



- Measuring overall WOM performance
  - Photon capture efficiency, attenuation effects, (…)

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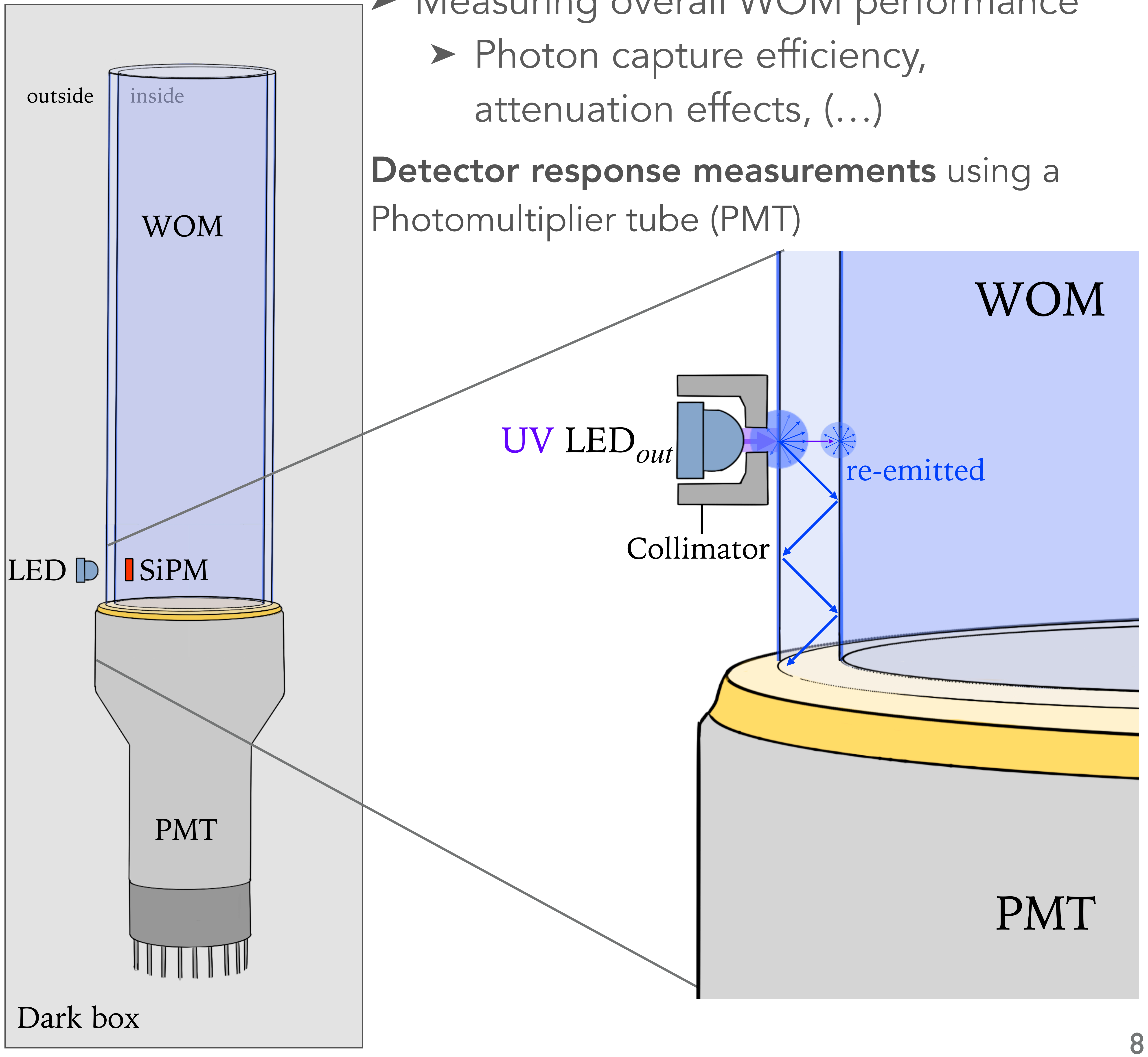
Detector response measurements using a Photomultiplier tube (PMT)



FOLLOWING UP ON MASTER THESIS: WOM QUALITY CONTROL

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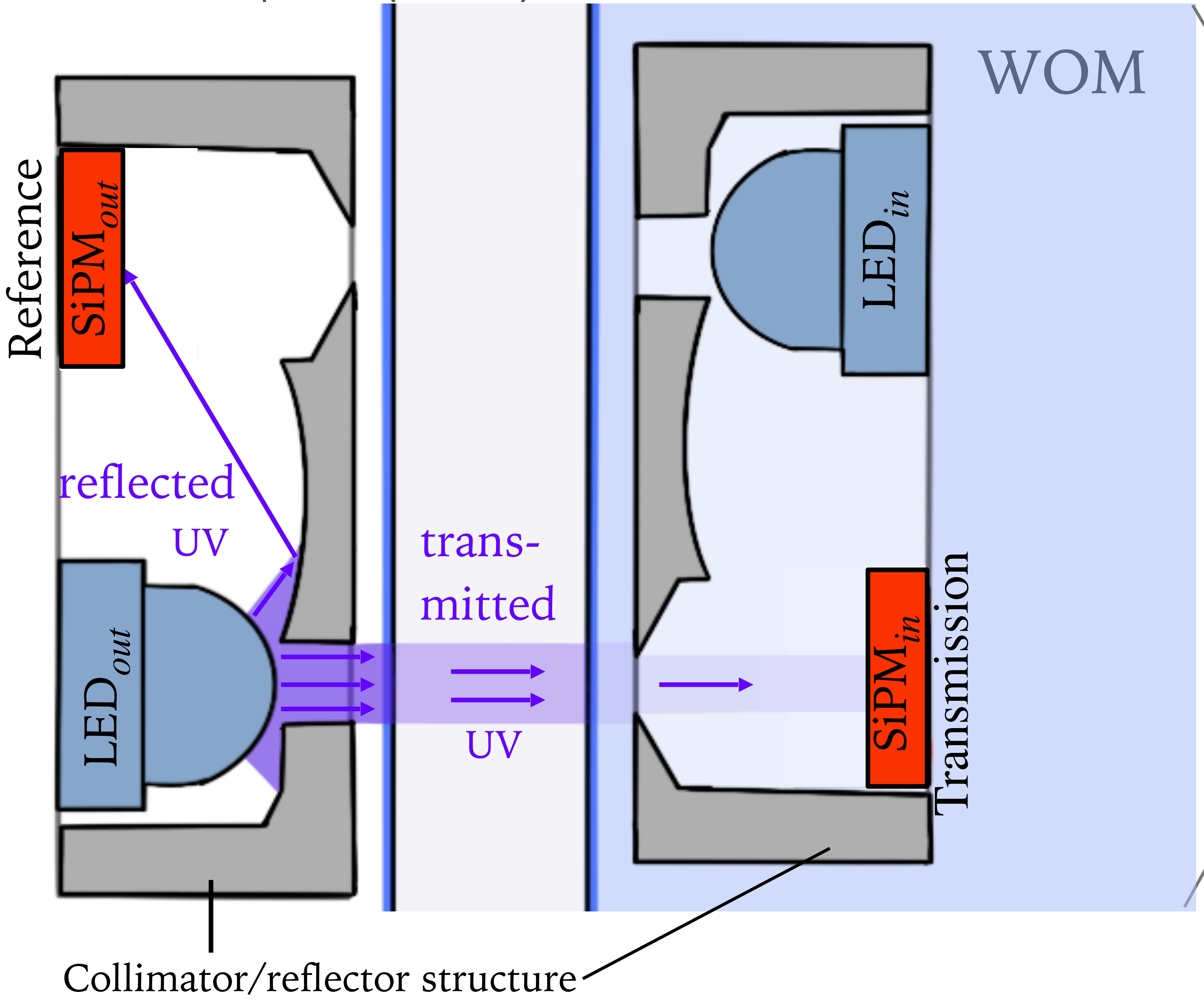
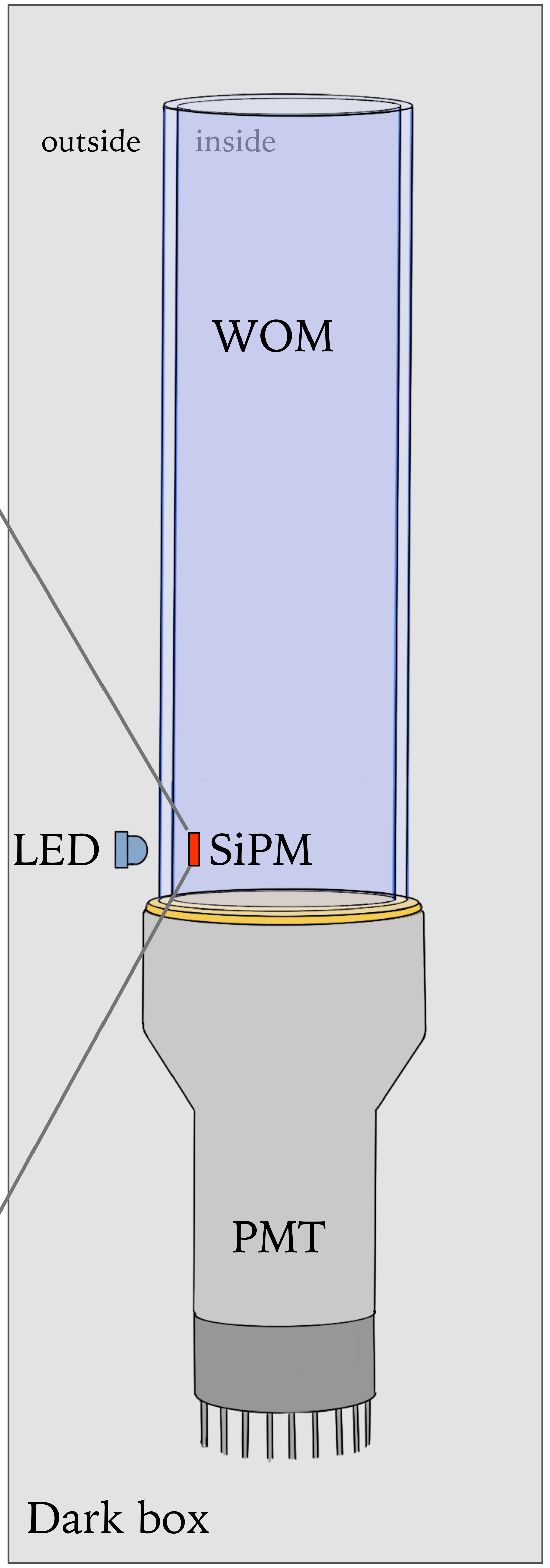
Transmission measurements using Silicon Photomultipliers (SiPMs)





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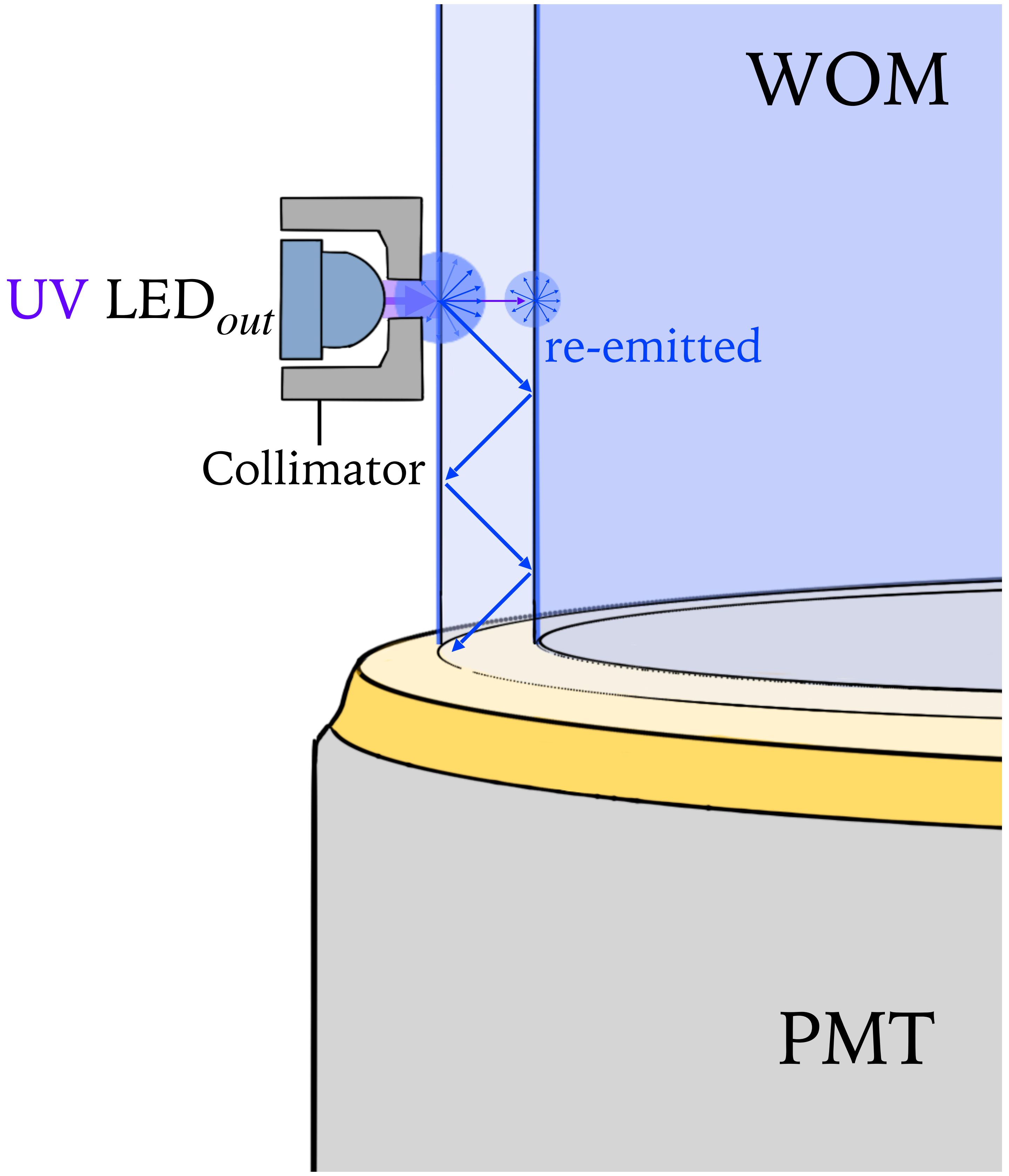
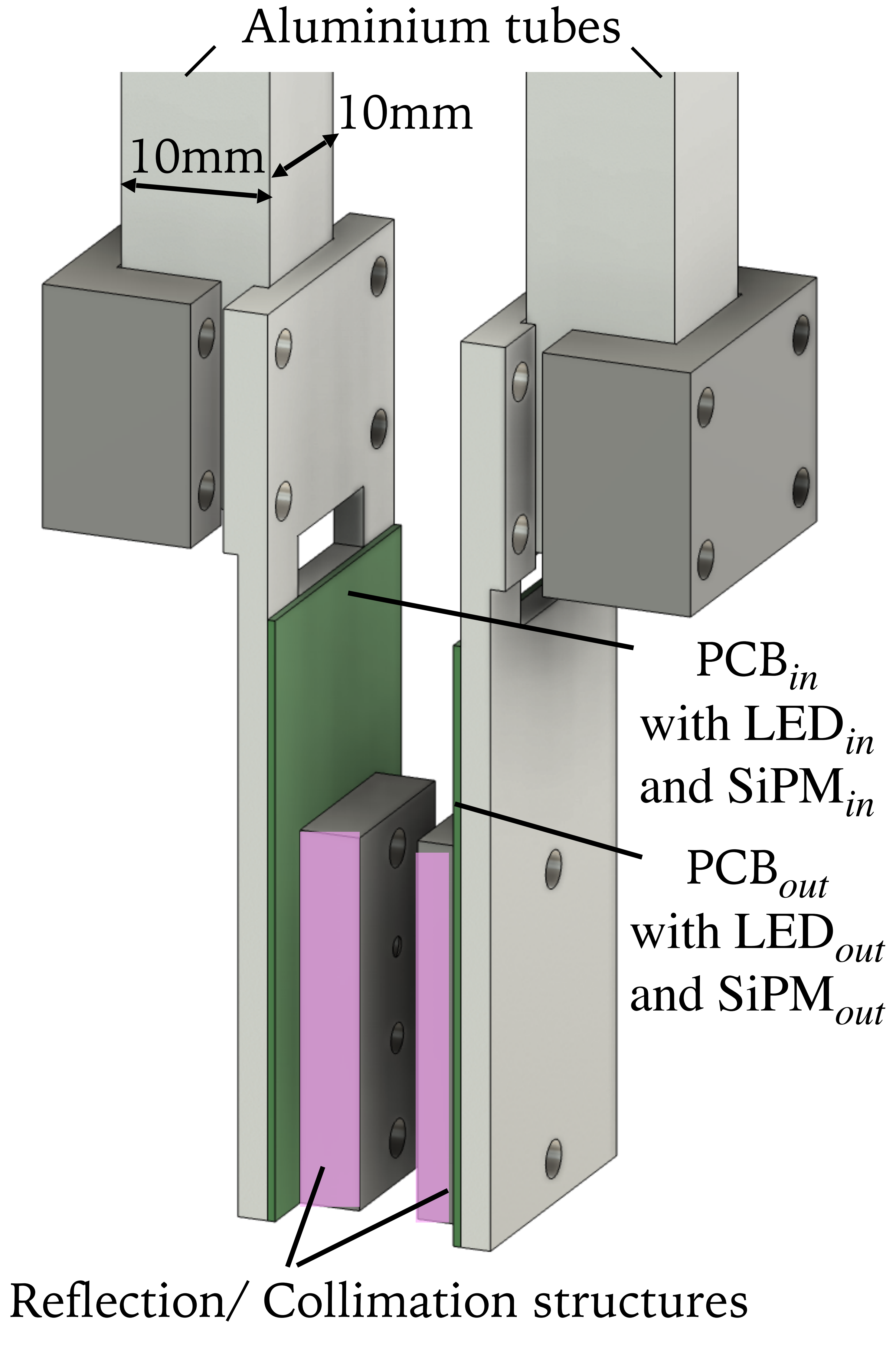


WOM QUALITY CONTROL - SET-UP IMPLEMENTATION



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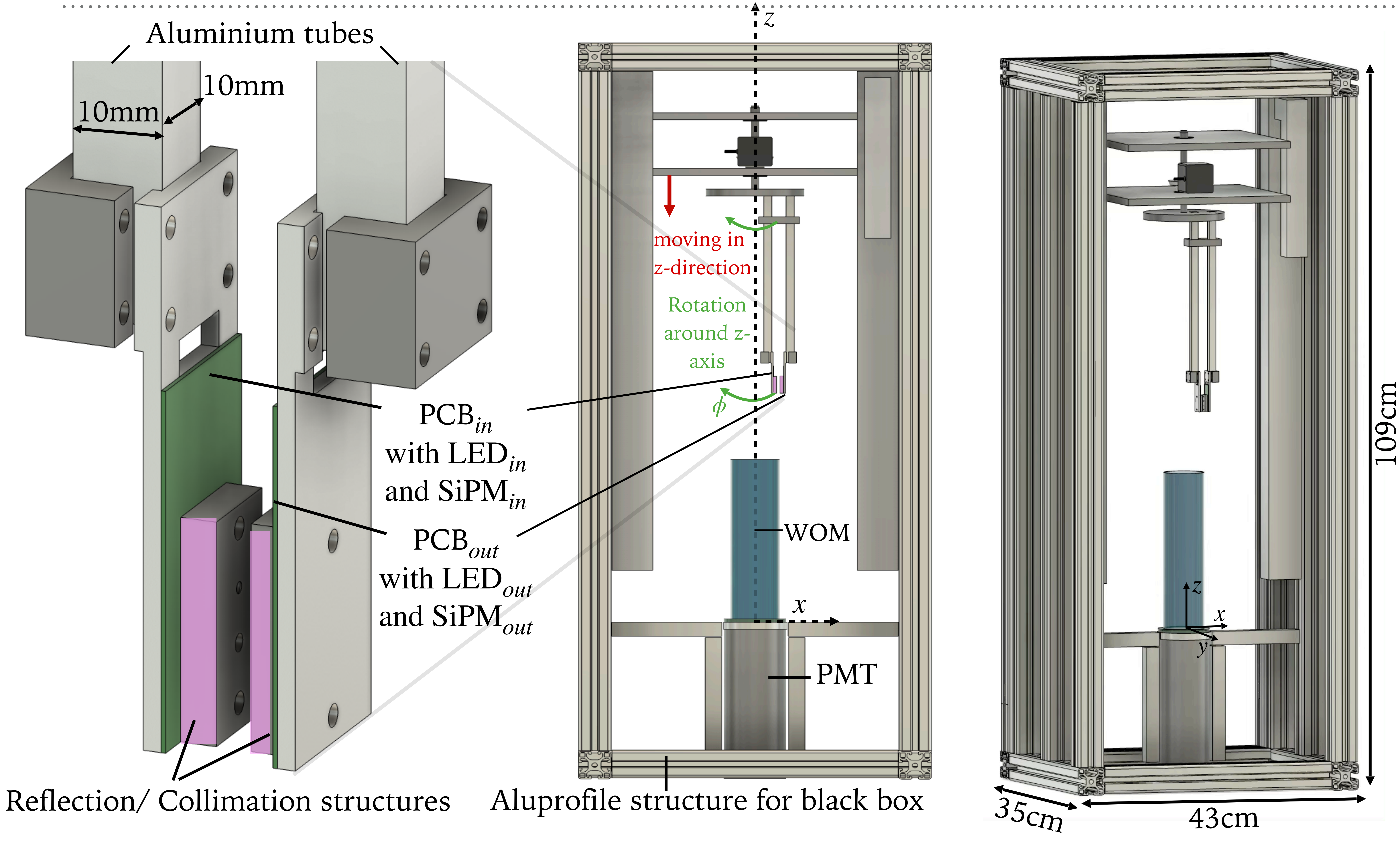

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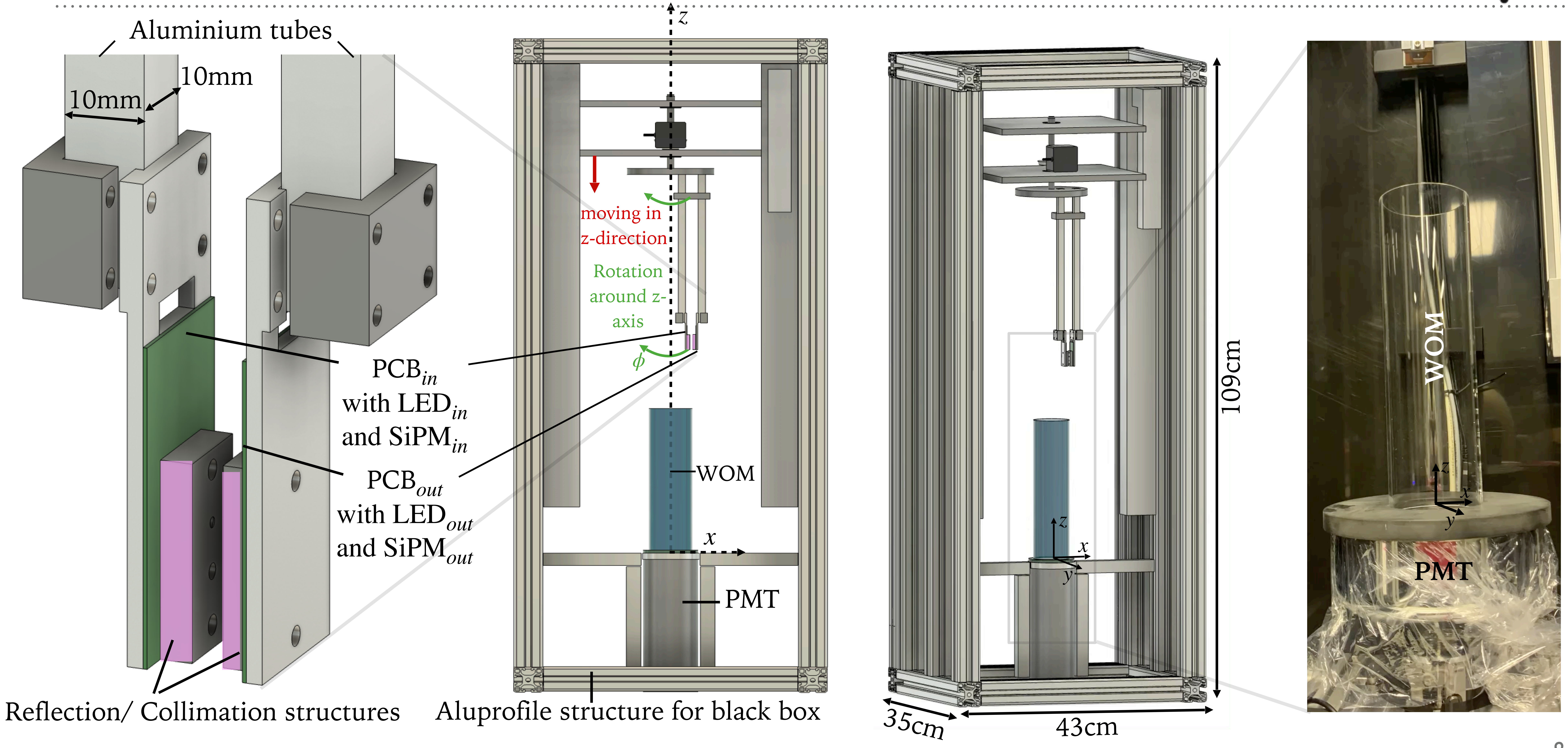


OUTLOOK – NEXT STEPS

1. Preparation of WOM quality control:

- Finalize WOM Quality Control setup
  - SiPM integration, optimize optical coupling method (WOM to PMT)
- Perform first tests on WOMs

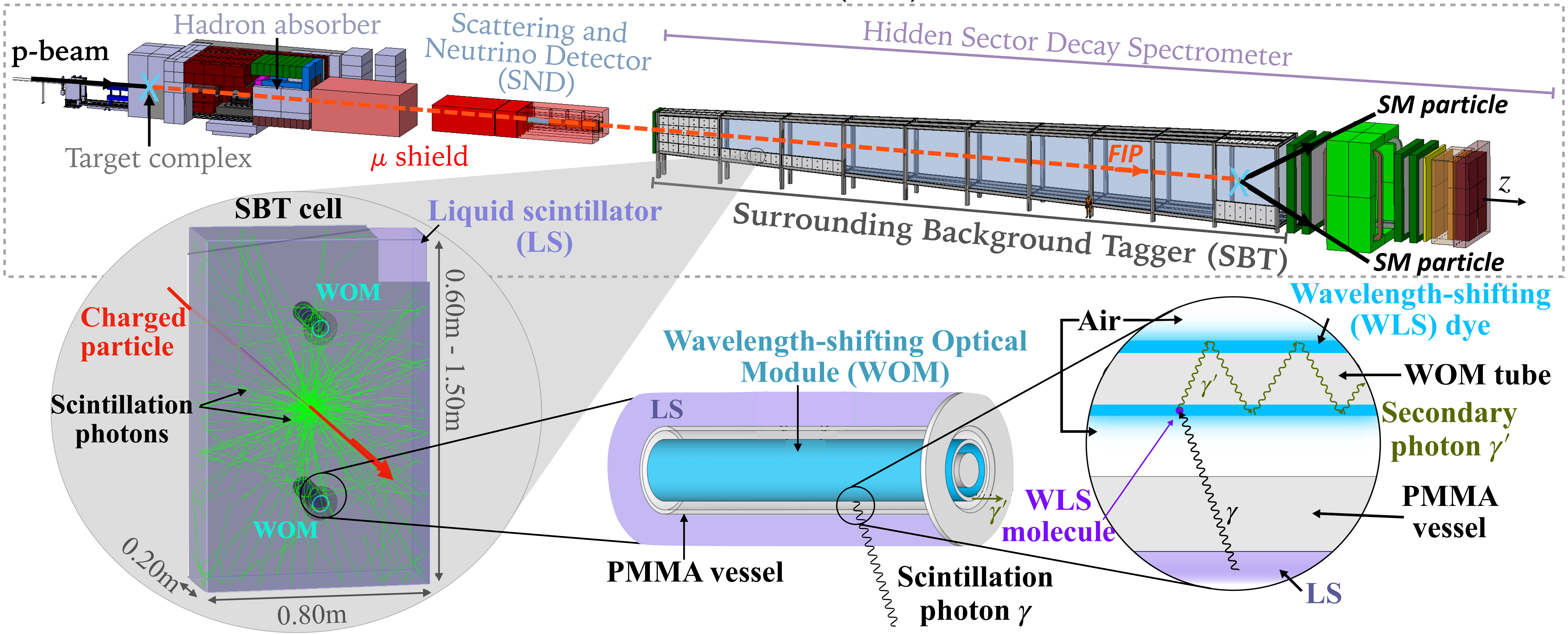
2. Start with simulation studies of background processes

- Background Suppression with SBT
  - Simulation with larger test samples to understand efficiency over 15 years of running for SHiP

https://get.pxhere.com/photo/sea-coast-ocean-horizon-sunrise-sunset-boat-morning-ship-dusk-boot-evening-mediterranean-vehicle-mast-sailing-calm-bay-rest-sailboat-sail-sailing-vessel-quiet-watercraft-mood-sailing-ship-afterglow-evening-sky-zweimaster-743483.jpg

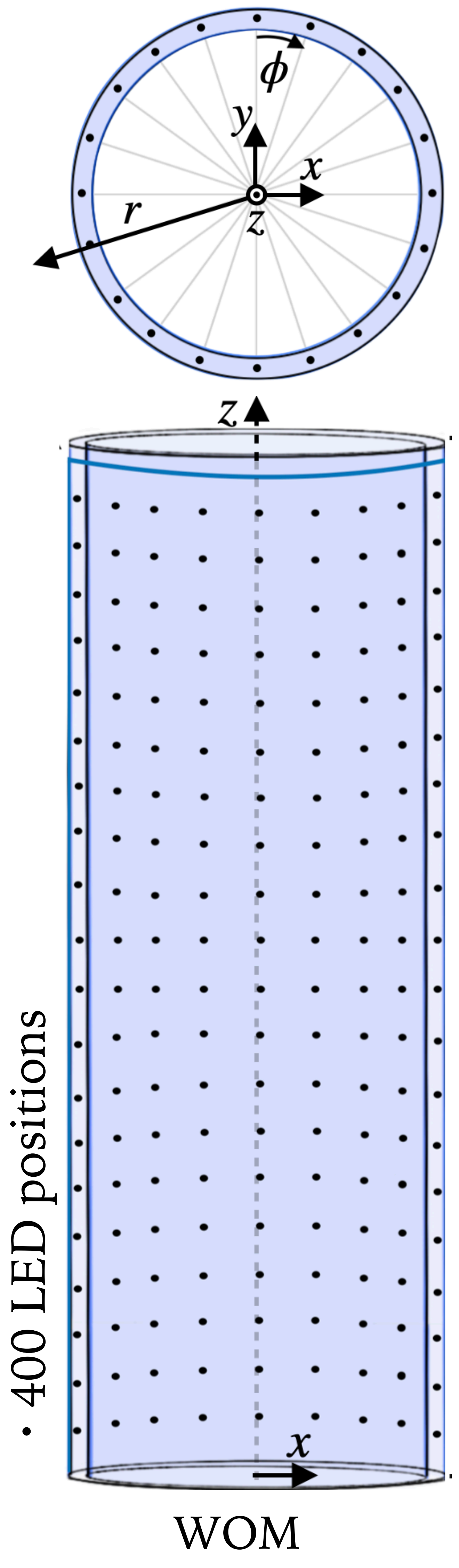
THANK YOU FOR YOUR ATTENTION— QUESTIONS?

Search for Hidden Particles (SHiP) Detektor



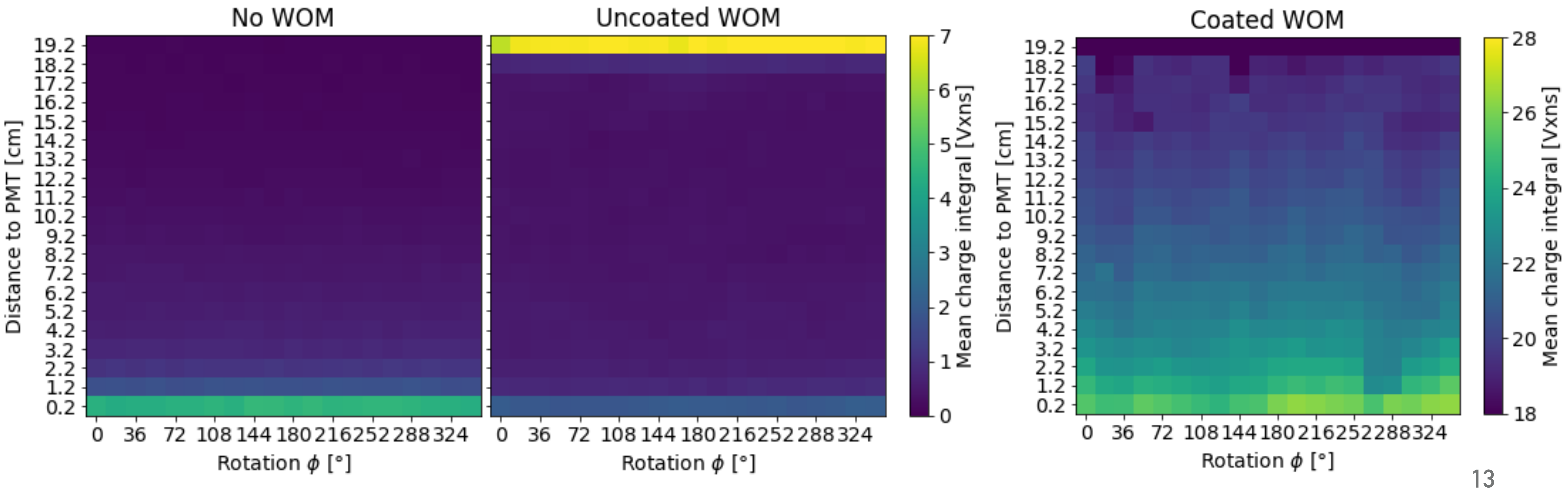
APPENDIX

WOM QUALITY CONTROL - MEASUREMENTS

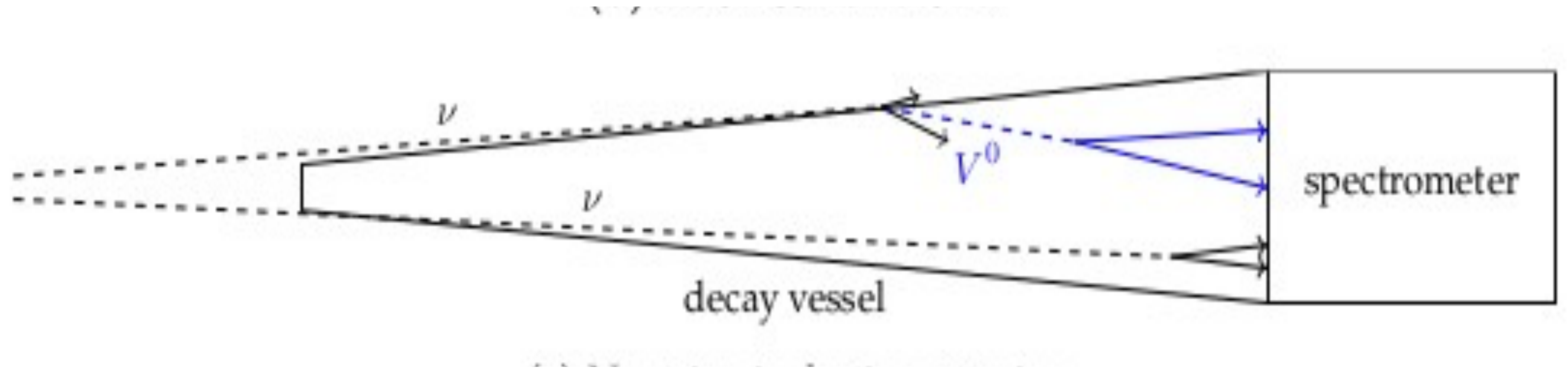


- For each position on each WOM ~30 LED pulses measured and integrated over time
- Measurements performed to ensure high quality production
- Test reduction of the WOM quality due to aging, transport and fastening in SBT cell

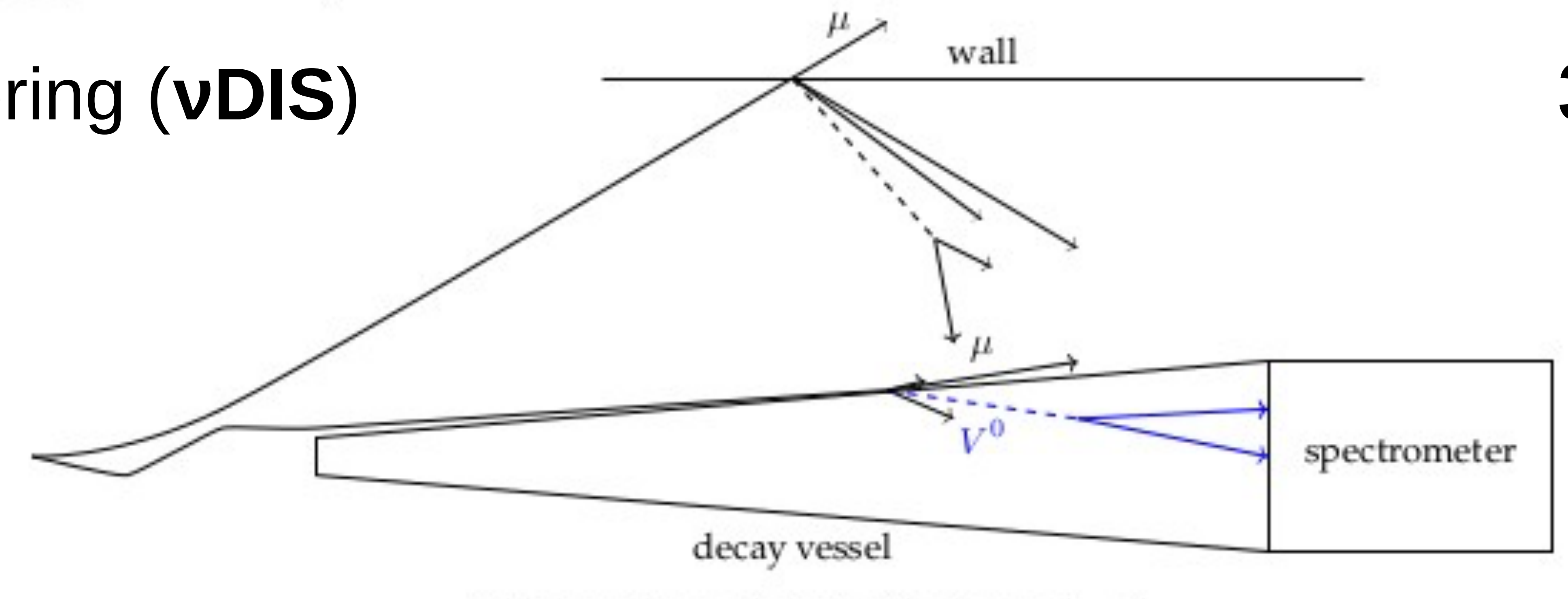
Measurements at 400 Positions for different configurations of the setup:



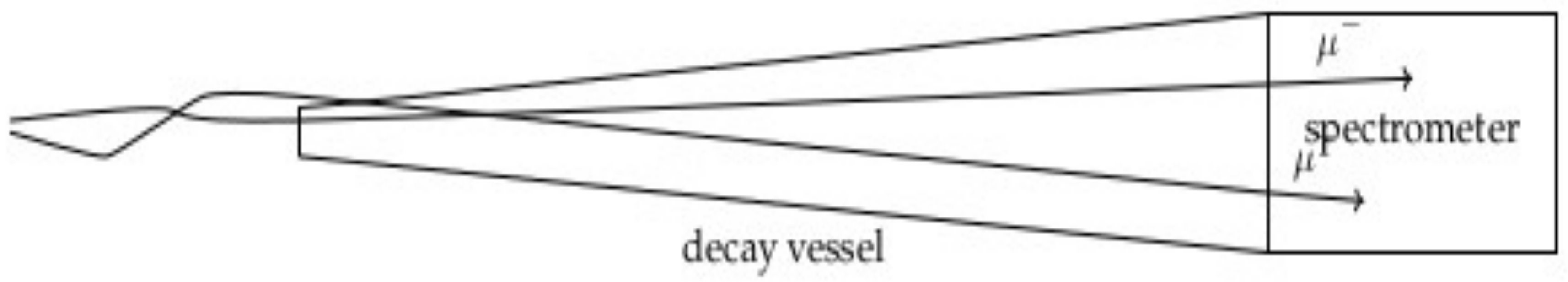
Background in SHiP



1) Neutrino Deep Inelastic Scattering (**νDIS**)



2) Muon Deep Inelastic Scattering **(μDIS)**



3) Muon Combinatorial

Extremely efficient and redundant background suppression allows for great physics performance in SHiP

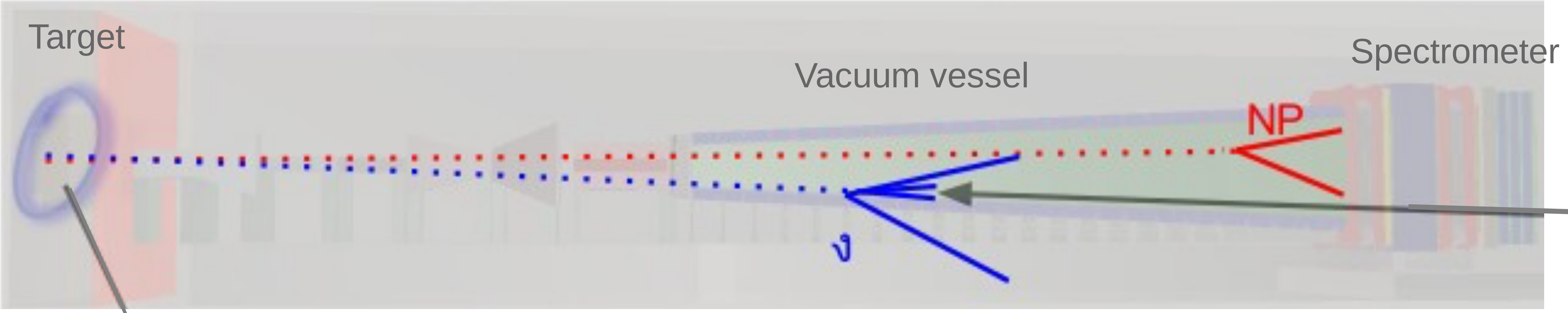
Current SBT veto criteria:

To veto any candidate for signal if there is SBT activity above the energy deposition threshold → **Basic SBT**

Simulation studies done using FairSHiP, framework integrating ROOT, Pythia6, Pythia8, Genie & Geant4

BG Simulation (νDIS)

How do we simulate the ν background in SHiP?



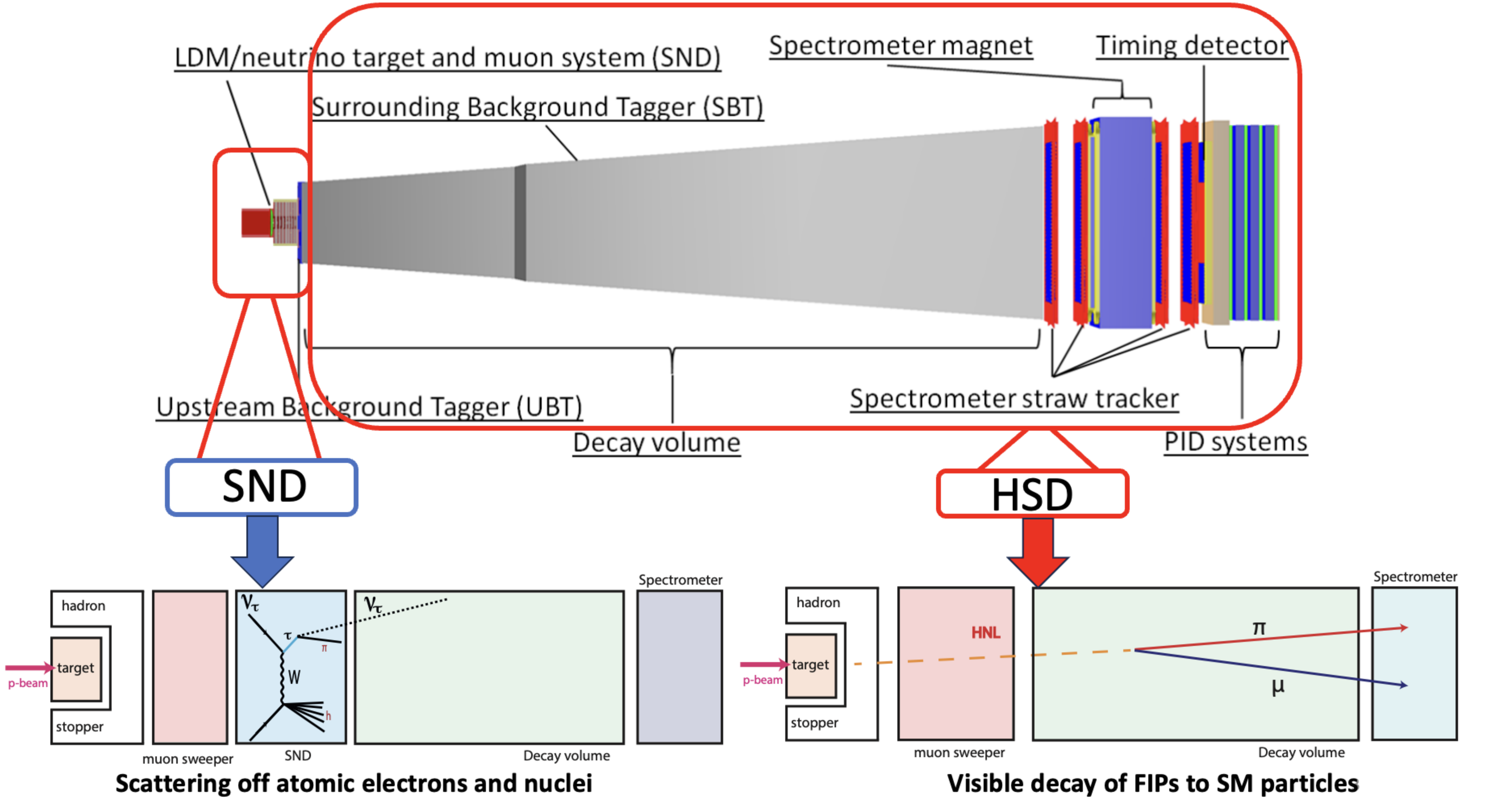
1. POT interactions simulated with Pythia8, momentum dist. of outcoming ν extracted.
2. Spectrum of neutrinos passed to GENIE to generate ν interactions.
3. Particles produced in interactions passed to GEANT4 for detector response.
4. Using a P/Pt distribution event positioned in geometry based on weight, described by local material density along trajectory and track length.

Background in SHiP

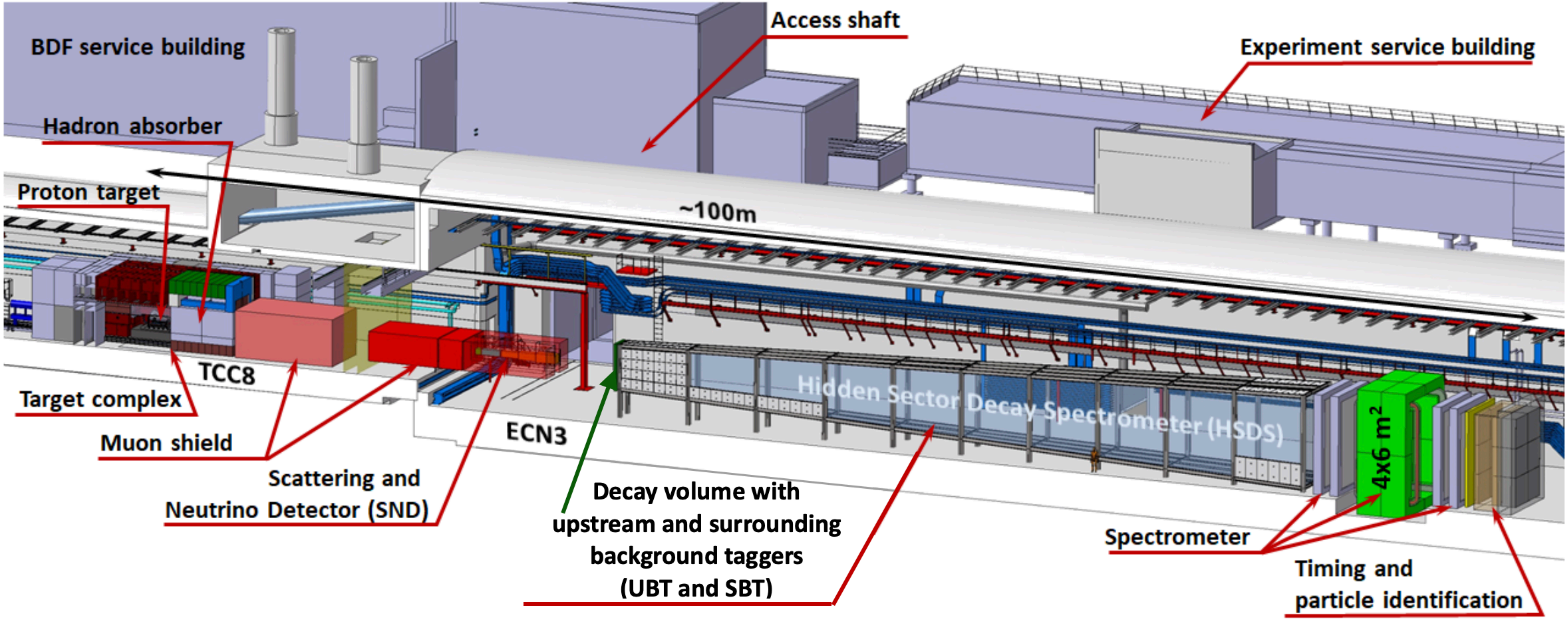
Expected background in ECN3 at 90% CL for 2 x $10^{20\ POT}$ interactions after applying Preselection, timing, UBT and BasicSBT@45 veto:

Background Source	Expected Events	
Muon combinatorial	2.7 x 10^{-3}	
Neutrino DIS	fully reconst.	partially reconst.
	< 0.1	< 0.3
Muon DIS (factorisation)	< 10^{-4}	< 10^{-2}

Detectors @ SHiP



SHIP DETECTOR STRUCTURE



SENSITIVITY OF SHIP

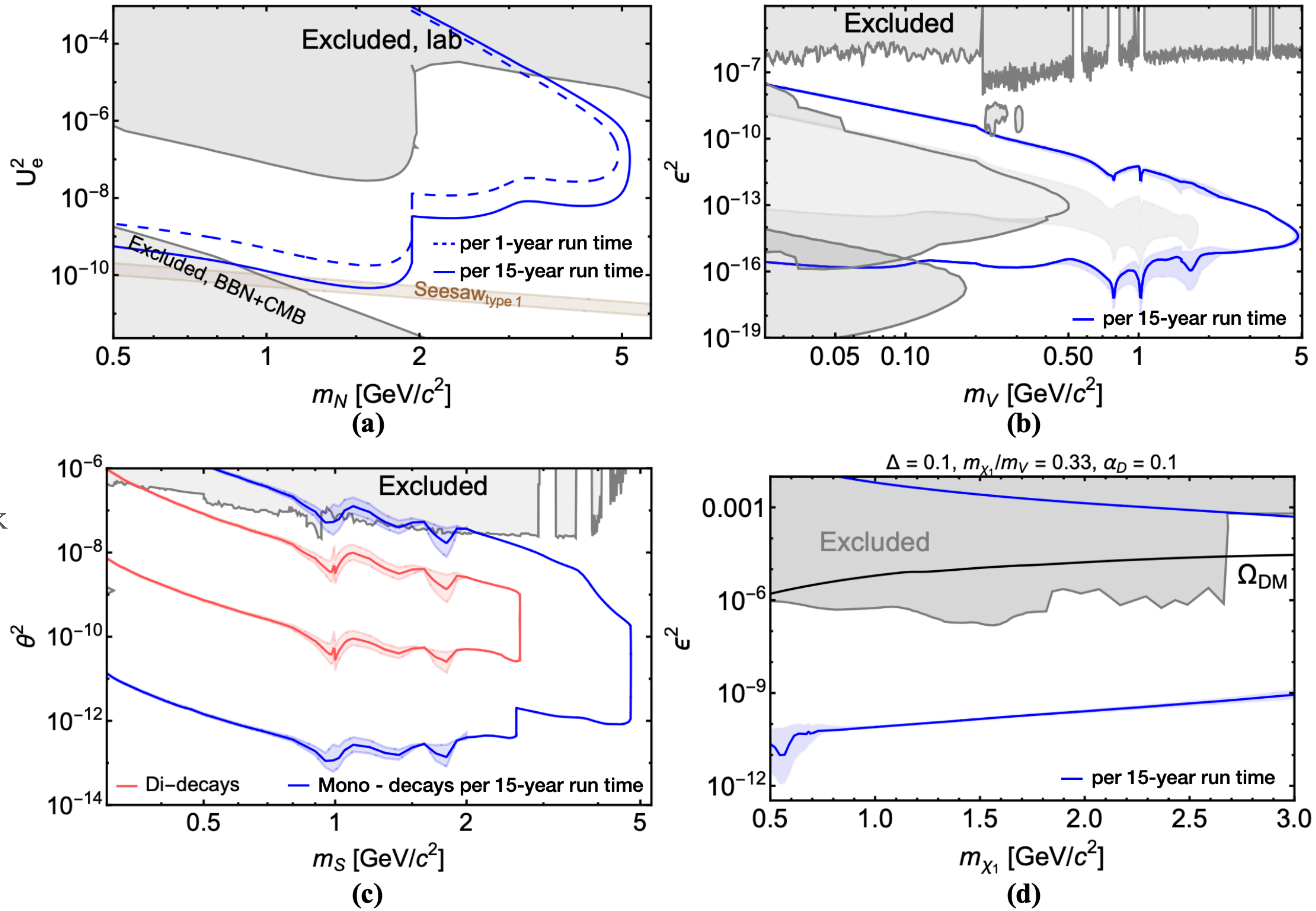
➤ https://cds.cern.ch/record/2929845

a) **Heavy Neutral Leptons (HNLs)**

b) **Dark Photons**

c) **Higgs-like scalars S** with the trilinear coupling to the Higgs boson

d) **Inelastic dark matter** coupled via dark photons



REFERENCES

- Alessia Brignoli. Cheapcal (ap 2.4). https://indico.desy.de/event/33151/contributions/116477/attachments/71726/91623/20220221_High-D_Consortium-CheapCal_prototypeABrignoli.pdf, 2022.
- DuPont, 273, Baeul 1-ro, Yuseong-gu, Daejeon, 34036 Korea. DuPontTM Tyvek® 1073D Product Properties - Metric Units, 2019.
- Valerian v. Nicolai. First test-beam measurements with a position-sensitive plastic scintillator detector. Bachelor's thesis, Humboldt University Berlin, 11 2024.
- Christian Scharf. Wavecatcher analysis. https://wavecatcher-analysis.web.cern.ch/
- Ben Skodda. Light yield and spatial resolution of a plastic scintillator detector structured with wavelength-shifting fibers. Master's thesis, Humboldt University Berlin,2023.
- [50] JAY W. GRATE and OLEG B. EGOROV. 14 - automated radiochemical separation, analysis, and sensing. In Michael F. L'Annunziata, editor, Handbook of Radioactivity Analysis (Second Edition), pages 1129–1164. Academic Press, San Diego, second edition

REFERENCES

- S. Alekhin et al. A facility to search for hidden particles at the CERN SPS: The SHiP physics case. Reports on Progress in Physics, 79(12), October 2016. doi: 10.1088/0034-4885/79/12/124201. URL http://dx.doi.org/10.1088/0034-4885/79/12/124201.
- C. Ahdida et al. The SHiP experiment at the proposed CERN SPS beam dump facility. The European Physical Journal C, 82(5), 2022. doi: 10.1140/epjc/s10052-022-10346-5. URL https://doi.org/10.1140/epjc/s10052-022-10346-5.
- P. Santos Diaz and R. Jacobsson. Introduction and SHiP infrastructure overview. 32nd SHiP Collaboration Meeting, 1st Infrastructure workshop, CERN, Geneva (Switzerland), 2025. URL https://indico.cern.ch/event/1516350/contributions/6386824/attachments/3029072/5346856/Introduction%20&%20SHiP%20infrastructure%20overview.pdf.
- SHiP Collaboration HI-ECN3 Project Team. SHiP experiment at the SPS Beam Dump Facility. European Strategy for Particle Physics Update 2026, 2025. URL https://cds.cern.ch/record/2929845.
- A. Hollnagel. Liquid Scintillator Surrounding Background Tagger: Detector and Infrastructure. 32nd SHiP Collaboration Meeting, 1st Infrastructure workshop, CERN, Geneva (Switzerland), 2025. URL https://indico.cern.ch/event/1516350/contributions/6386944/attachments/3029341/5348333/2025-03-11_ship-infrastructure-ls-sbt_.pdf.